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OUTLINE AND SUMMARY OF A STUDY OF MAGNITUDES IN THE GLOBULAR CLUSTER MESSIER 13.

BY HARLOW SHAPLEY.

The measurement of the light intensity of a star as recorded by an ordinary photographic plate which is sensitive to blue light and by one especially prepared so as to be sensitive to yellow or mean visual light yields at once an indication of the star's color. In fact, this color-index, which is simply the difference between photographic and photovisual magnitude, not only defines the color of a star but gives also the spectral type as soon as due allowance is made for certain factors (size of the stars, for instance, and scattering of light in space) which may affect color without having a corresponding influence on the class of spectrum. For faint objects in crowded regions, such as the individual stars in stellar clusters, the color-index method is the best available for the determination of spectral type, and it gives at the same time values of the brightness in a standard magnitude system. Until recently, however, even this method could not be used for it necessarily depends upon accurate scales of magnitudes for the faint stars.

The importance of a special investigation of clusters lies in the fact that each globular system is a distinct stellar unit, and any light thrown on the structure or development of such groups must reflect on the structural characteristics of the local system of which the Sun is a member. One great advantage in studying stellar problems thru the agency of clusters is that their distances are so great that in statistical work all the stars of each one may be treated as at the same distance from the Earth. In other words, the distance factor is eliminated, and the measured apparent magnitudes differ only by a constant from absolute magnitudes. Consequently, in all correlations of brightness with other properties, such as distribution, color, and light variations, we are dealing directly with physical characteristics of the stars.

The derivation of magnitudes in globular clusters, previous to the work now in progress at Mount Wilson, has been based upon more or less uncertain standards and has made no pretense to accuracy. The studies of clusters, indeed, have chiefly been concerned with general descriptive work, the measurement of positions, the observation of variables, and theoretical discussions of laws of stellar distribution. The investigation at Mount Wilson aims mainly at the measurement of magnitudes and colors and the discussion of the problems arising in the course of the study.

The great globular cluster in *Hercules,* Messier 13, was placed first on the observing list. The spectra of a few of its stars had been photographed by Pease, and Barnard had observed conspicuous differences in color. Two catalogs of the positions of several hundred of the brightest objects have been made at Potsdam, and a number of investigations of the distribution of the stars are on record. For different parts of the work of forming a catalog of magnitudes twelve plates were secured at the principal focus of the 60-inch reflector, all but three of which contain exposures on the Polar Standards as well as on the cluster. The magnitude scales and zero points were thus transferred directly to the cluster from the North Pole. The tabulated magnitudes are based on four plates, the zero points are checked by four others, and additional photographs were used for the study of the variables and for determining the brightness of stars too faint to appear on the standard magnitude plates. By far the largest part of such work in globular clusters is in the identification and measurement of the stars. In deriving values for 1300 stars in Messier 13 more than ten thousand estimates and measures of magnitude were necessary. The detailed account will appear as No. 116 of the Contributions from the Mount Wilson Solar Observatory. The remainder of the present paper is devoted to a general summary of the investigation.

1. From an analysis of the residuals small systematic errors related to distance correction, astigmatism, and length of exposure are found, but none is important. The most serious difficulty involves the probable influence of the Eberhard effect in and near the center of the cluster. The relative error in the zero points of the two magnitude scales does not exceed a few hundredths of a magnitude, and no appreciable scale-divergence is found.

2. The probable error of an average color-index is about six hundredths of a magnitude. This does not entirely include the systematic error allied to the color excess in the center, but is valid for distance greater than 2′. From Table I, which summarizes a study of the errors, we find that for ninety-five per cent of the magnitudes used in the statistical discussions the average probable error is less than a twentieth of a magnitude.

TABLE I.

	PHOTOGRAPHIC		PHOTO-VISUAL	
	Whole Cluster	Distance > 2′	Whole Cluster	Distance > 2′
Probable error:				
One plate...........	$\pm0^{m}.068$	$\pm0^{m}.057$	$\pm0^{m}.046$	$\pm0^{m}.044$
Two plates..........	±0 .048	±0 .041	±0 .033	±0 .031
Corrected for systematic deviations:				
One plate...........	±0 .061	±0 .044	±0 .040	±0 .035
Two plates..........	±0 .043	±0 .031	±0 .029	±0 .025

3. A catalog of the photographic and photo-visual magnitudes of about 1300 stars has been prepared. Owing to the probable presence of systematic error in the magnitudes in the denser central regions, the lists published in Contribution No. 116 contain only about 650 stars; publication of the remainder awaits further investigation of suspected errors. Probably not more than 18 of the magnitudes refer to superposed non-cluster stars.

4. Discarding incomplete or doubtful results, 1049 magnitudes and color-indices are available for statistical investigation, of which 495 are outside the central region. The range of observed photo-visual magnitudes is from 11.9 to 16.8; but all of the stars are included only down to magnitude 15.5.

5. Five new variable stars have been discovered, making a total of seven in the cluster. The periods are probably short, and there is evidence that all are bluer at maximum than at minimum, suggesting the Cepheid type of variation. The two previously known variables are almost certainly Cepheids.

6. The values of the color-index in the cluster range from —0.52 to +1.96, with the greatest frequency about +0.90. Excluding the zone within 2′ of the center, the upper limit is +1.45, with greatest frequency near +0.70. More than

17 per cent of the values are negative (outside distance 2′), and there appears to be no reason for attributing this result to error of any kind. The frequency of the colors for the whole cluster and for the region more distant from the center than 2′ is shown in Table II. Color class may be taken as closely analogous to spectral class. Tabulated quantities are numbers of stars.

TABLE II.

	Color Class												
Region	b0 to b5	b5 to a0	a0 to a5	a5 to f0	f0 to f5	f5 to g0	g0 to g5	g5 to k0	k0 to k5	k5 to m0	m0 to m5	m5 to m9	All Colors
All of cluster..	22	91	83	71	99	223	243	114	45	33	15	5	1049
Distance >2′...	16	70	36	27	50	135	115	33	9	4	..	.	495

7. The size and distribution of the color-indices are what might be expected on the basis of no selective scattering of light in space. At least the absorption in the direction of the *Hercules* cluster must be less than +0.0001 mag. for each unit of distance ($\pi = 0''.1$). The values derived by Kapteyn, Jones, Van Rhyn, and some others are impossible in this case, even with the most favorable assumptions as to the distance of the cluster.

8. The average color index at greater distances from the center than 2′ is +0.55, corresponding to spectrum F4. Toward the center of the cluster it increases to at least +1.3, and no negative values appear. The increase is present for all magnitudes and is probably to be interpreted as a systematic photographic error, perhaps the Eberhard effect. If the phenomenon is real, however, it would indicate an absorption within the cluster, or a preferential concentration of red stars in that region.

9. The possible existence of "cluster absorption" suggests that for lower galactic latitudes there may be a measurable amount of space absorption; observations are being made for the purpose of testing this hypothesis.

10. The determination by Pease of spectra of individual stars in the cluster gives results confirmatory of the direct interpretation of color class as spectral type, and verifies the excess of color in the center.

11. Of the four hundred faintest stars measured in the cluster, 85 per cent are bluer than the color class g0, which

corresponds to solar spectral type; of the four hundred brightest stars 75 per cent are redder than g0. An analogous result holds for the outer regions alone. The average magnitude for each color class in the whole cluster and in the region outside 2′ is shown in Table III.

TABLE III.

	Color Glass							
Region	b	a	f	g	k	m	All Colors	Average Color Class
All of cluster..	15.19	14.99	14.78	14.15	13.34	12.96	14.50	f6
Distance >2′...	15.20	15.01	14.85	14.28	12.74	.....	14.71	f3

12. The almost linear decrease of color-index with decreasing brightness is in evidence in all regions of the cluster. The phenomenon probably has an important significance in considerations of the order of development of giant stars.

13. Between photo-visual magnitudes 16.0 and 16.8 only four out of the special list of a hundred faint stars have color-indices greater than half a magnitude, and none is found redder than the Sun.

14. There is some evidence that the brighter stars are more strongly condensed in the center of the cluster than the faint ones; at least the average magnitude is brighter, even without allowing for the color excess. Outside the central zone the cluster stars seem to be very thoroly mixed with respect to magnitude and color.

15. The laws connecting star-density and distance cannot be determined until the phenomenon interpreted here as the Eberhard effect (which also depends on distance from the center) has been thoroly investigated; even neglecting this effect, the distribution laws ordinarily derived must be recognized as applying to only that very small percentage of all the stars which is represented by those of exceptionally high intrinsic brightness.

16. The probable distance of the *Hercules* cluster is estimated from considerations of its variable stars, its fragmentary luminosity curves, and the average apparent brightness of certain color groups. The parallax must be less than +0″.0001 and is probably greater than +0″.00001.

17. At the provisionally adopted distance of a hundred thousand light-years, the cluster would be more than a thousand light-years in diameter.

18. There seems to be reasonably clear evidence that this and similar globular clusters are very distant systems, distinct from our galaxy and perhaps not greatly inferior to it in size. The open clusters, on the other hand, seem to be relatively small parts of the local system; but further observation is necessary to make certain of this deduction.

In conclusion it may be stated that since the completion of the work on Messier 13 similar but less extensive studies have been made of six other globular clusters and of two open groups. The results from the globular clusters, so far as they have been analyzed, are in good agreement with those summarized above for Messier 13. The presence of blue stars and the absence of exceptionally large color-indices indicate that the effectiveness of interstellar media as light scattering agents is very slight. In particular, the phenomenon of decreasing color-index with decreasing brightness holds for such clusters as Messier 3, 5, and 15, and is very probably a general characteristic of all globular systems. August 1916.

A LUMINOUS OBJECT SEEN ON MAY 4, 1916.

By C. D. Perrine.

About 9^h 10^m in the evening of May 4th (Córdoba mean time) Dr. Glancy called my attention to a peculiar object in the southeastern sky.

It was then a bright streak just below *α Pavonis,* sensibly straight, about 8° or 10° long and one-half to one degree in width. It was more sharply defined toward the west, that extremity resembling the head of a large bright comet, but without any well defined condensation or nucleus. In general appearance to the naked eye and with the exception of a changed position it was an exact counterpart on a smaller scale of Halley's comet when this object was near to the Earth and its head near enough to the horizon to suffer greatly by absorption from the atmosphere.

After a few minutes' examination with field glasses a series of pointings was made as long as it could be seen with